

Method for operating an internal combustion engine

- 5 The invention relates to a method for operating an internal combustion engine according to the preamble of claim 1, in particular an auto-ignition internal combustion engine with direct injection.
- 10 In direct-injection internal combustion engines with auto-ignition, lean homogeneous fuel/air mixtures are often made to auto-ignite so that high efficiency levels and improved exhaust emissions are obtained. In such internal combustion engines which are referred to
- 15 as HCCI or PCCI internal combustion engines, also referred to as internal combustion engines with spatial ignition combustion, a lean basic mixture of air, fuel and retained exhaust gas is generally formed at partial load and auto-ignited. In the case of full load, a
- 20 stoichiometric mixture is frequently formed and spark-ignited because at high loads steep rises in pressure could occur in the combustion chamber due to the auto-ignition and these would adversely affect the operation.
- 25 Patent DE 198 10 935 C2 discloses a method for operating an internal combustion engine which operates according to the four stroke principle and in which a homogeneous lean mixture of air, fuel and retained
- 30 exhaust gas is formed and is burnt after compression ignition. In this context, there is an intermediate activation phase in order to expand the operating range of the motor with compression ignition. During the compression of the retained exhaust gas, an activation
- 35 fuel quantity is injected into the combustion chamber and distributed as homogeneously as possible in the combustion chamber with the remaining components of the mixture. In this way thermal energy is supplied to the mixture by power and compression so that a chemical

reaction or ignition is initiated in the vicinity of the top dead center of the charge change. The ignition time of the fresh charge can be controlled during the main compression by means of the time and the quantity
5 of the activation injection.

According to the current state of the art, selective control of the combustion described above can be achieved only with difficulty since the time of auto-
10 ignition depends very greatly on the parameters of the engine and the ambient conditions. For this reason, attempts are made to control the initiation of the compression ignition using suitable control variables, for example by means of a cylinder pressure signal.
15 Such concepts are, however, associated with a high degree of expenditure on engine control technology which leads to a rise in the manufacturing costs of such internal combustion engines.

20 The invention is therefore based on the object of providing a method for operating an internal combustion engine in which reliable operation with auto-ignition is ensured.

25 This object is achieved by means of a method having the features of claim 1.

The method according to the invention is distinguished by the fact that exhaust gas is retained in the
30 combustion chamber of an internal combustion engine and is compressed during a charge change, a first fuel quantity being injected into the retained exhaust gas by means of direct fuel injection. A second fuel quantity is subsequently fed to the combustion chamber,
35 preferably during the intake phase and/or in an initial part of the compression phase, so that a homogeneous fuel/air mixture is formed in the combustion chamber. In this context, an auto-ignition time of the fuel/air mixture which is formed from the first and second fuel

quantities is set as a function of a quantity ratio of the first fuel quantity to the second fuel quantity.

5 The injection of the first fuel quantity into the retained exhaust gas brings about optimum homogenization or preconditioning of the first fuel quantity, which leads to an increase in mixture reactivity of the fuel/air mixture which is formed from the first and second fuel quantities. This favors the
10 inception of the auto-ignition, in particular at operating points with a low exhaust gas temperature. The first fuel injection is preferably performed between the closing of an outlet valve and the opening of an inlet valve. Depending on the injection time of
15 the first fuel quantity, the preconditioning effect can extend beyond pure homogenization. If, in particular, the fuel is injected into the retained exhaust gas before the top dead center of the charge change, said exhaust gas also containing residual air, conversion-
20 like reactions can occur, as a result of which the temperature of the mixture can be influenced, in particular increased.

In a refinement of the invention, the quantity ratio of
25 the first fuel quantity to the second fuel quantity of 1:100 to 2:1, in particular of 1:5 to 1:3, is set. As a result the preconditioning effect can be adapted to the current operating point by means of the first fuel quantity. The injection of the second fuel quantity
30 preferably takes place in synchronism with induction so that the reactivity of the mixture which is set by means of the first fuel quantity is neither increased nor decreased. The second fuel quantity is thus primarily used to set a desired load.

35 According to a further refinement of the invention, a center of gravity of the combustion is set by injecting a third fuel quantity, which is carried out after the injection of the second fuel quantity ends and

preferably before a top dead center of the ignition. The third fuel quantity is aimed at reducing the reactivity of the total cylinder charge in particular under high loads. This is intended to reduce high
5 burning speeds and large pressure rises in the combustion chamber.

In a further refinement of the invention, the period of combustion is set as a function of the third fuel
10 quantity and its injection time. With the reduction in the reactivity of the mixture which is brought about by the third fuel quantity the burning through of the cylinder charge is slowed down so that, depending on the injection time of the third fuel quantity, the
15 combustion period can be optimized as a function of the load.

Further features and material combinations result from the description. A specific exemplary embodiment of the
20 invention is illustrated in a simplified form in the drawing and explained in more detail in the following description.

The single figure is a schematic illustration of a
25 cylinder pressure profile of an internal combustion engine which is operated either with auto-ignition and/or spark ignition.

An exemplary internal combustion engine with direct
30 injection comprises at least one cylinder in which a piston is secured in a longitudinally displaceable fashion, at least one inlet valve, one outlet valve, a fuel injector and optionally an ignition source being provided per combustion chamber. The combustion chamber
35 of the internal combustion engine is closed off at the top by a cylinder head, the piston delimiting the combustion chamber at the bottom. The inlet and outlet valves are opened and closed by an activation device, a control unit correspondingly controlling the opening

and closing times of the inlet and outlet valves in accordance with the current operating point. The internal combustion engine preferably operates according to the four-stroke principle.

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In a four-stroke method, one stroke corresponds to one full stroke of the piston. According to the figure shown, the profile of the combustion chamber pressure is set during one working cycle of the internal combustion engine according to the invention. The working cycle of the internal combustion engine which is composed of four strokes corresponds to one combustion cycle, a combustion cycle starting with a first intake stroke at a top dead center LOT of a charge change at which the piston moves as far as a bottom dead center UT in a downward movement. During the intake stroke, the combustion chamber is supplied with combustion air, during which process according to the invention a specific quantity of exhaust gas is retained in the combustion chamber in an expulsion stroke of a previous working cycle.

The method according to the invention is aimed at setting a specific mixture reactivity of a fuel/air mixture which is formed from the first fuel quantity and a subsequent, second fuel quantity E2 by means of a first injection E1 which is input into the combustion chamber which is filled with retained exhaust gas. In this way, closed-loop or open-loop control is carried out on the inception of the auto-ignition. This is advantageous in particular at operating points with a low exhaust gas temperature since reliable operation of the internal combustion engine with compression ignition is made possible even in lower rotational speed and load ranges.

The first fuel quantity E1 makes available a relatively large amount of energy or a relatively high temperature level for a subsequent main combustion, allowing energy

loss due to the relatively small fuel quantity which is converted to be compensated when low engine loads are being implemented. As a result, the current operating range with compression ignition is made larger so that
5 further improved exhaust gas emissions can be obtained, for example in the idling mode.

The first fuel injection E1 is preferably performed between the closing of the outlet valve AS and the
10 opening of the inlet valve EÖ. Alternatively, the first fuel quantity can be injected into the exhaust gas retained in the combustion chamber during the expulsion stroke of the internal combustion engine between the closing of the outlet valve AS and 270° Ca before a top
15 dead center ZOT of the ignition.

Alternatively, the first fuel quantity E1 can be input into the combustion chamber in a range between the closing of the outlet valve AS and the top dead center
20 LOT of a charge change. As a result, the conversion-like reactions during the first fuel injection E1 are increased. The injection of the first fuel quantity E1 leads to conversion-like reactions with which the final temperature of the mixture is influenced. As a result,
25 the auto-ignition time is influenced. The first fuel quantity is preferably between 0% and 30% of the total fuel quantity, and the second fuel quantity can be between 30% and 100% of the total fuel quantity.

30 Inputting the second fuel quantity E2 into the combustion chamber forms the main mixture which is compressed in the compression stroke. During the compression stroke, the piston moves in an upward movement from the bottom dead center UT as far as the
35 top dead center ZOT of the ignition. The main mixture which is formed is ignited in a region of the top dead center ZOT of the ignition by the compression which is present. According to the invention, the auto-ignition time of the fuel/air mixture which is formed from the

first and second fuel quantities is set as a function of a quantity ratio $E1/E2$ of the first fuel quantity to the second fuel quantity. The quantity ratio $E1:E2$ of the first fuel quantity to the second fuel quantity is preferably between 1:100 and 2:1. A particularly advantageous preconditioning of the main mixture occurs with a quantity ratio $E1:E2$ between 1:20 and 2:1 or between 1:5 and 1:3. The second fuel quantity $E2$ is preferably injected into the combustion chamber in a range between 300° Ca and 120° Ca before the top dead center ZOT of the ignition.

While the combustion of the main mixture is still occurring, the piston expands in a downward movement as far as a bottom dead center UT. The center of gravity of the combustion can be optimized according to the invention by means of an injection of a third fuel quantity $E3$. According to the invention, the third fuel quantity $E3$ is input into the combustion chamber after the second fuel quantity $E2$ has ended. The third fuel quantity $E3$ is optionally injected before or after the inception of the auto-ignition, injection preferably occurring before the top dead center ZOT of the ignition so that the reactivity of the main mixture or of the total cylinder charge can be reduced or changed. The third fuel injection $E3$ can advantageously control the period of combustion as a function of its injection time and/or its quantity. As a result, steep rises in pressure in the combustion chamber are prevented and better exhaust gas emissions are thus obtained. The third fuel quantity $E3$ is preferably 0% to 30% of the total fuel quantity.

In the following expulsion cycle, the piston moves in an upward movement as far as the top dead center LOT of the charge change and expels the exhaust gases from the combustion chamber. The outlet valve is opened (AÖ) during the expulsion stroke so that the exhaust gases are expelled from the combustion chamber, early closing

of the outlet valve (AS) causing a specific quantity of exhaust gas to be retained in the combustion chamber.

According to the invention, the first fuel quantity E1
5 is converted in the region of the top dead center LOT
of the charge change so that preconditioning or
additional combustion causes the temperature of the
combustion chamber to be increased. This leads to an
increase in the pressure in the combustion chamber. The
10 conversion of energy in the region of the top dead
center LOT of the charge change also causes the
temperature of the exhaust gas retained in the
combustion chamber to be increased as a whole so that
the large thermal losses of the exhaust gas against the
15 walls of the combustion chamber, in particular in low
rotational speed and load ranges, are compensated. A
higher level of energy and a higher temperature are
thus available for the subsequent main combustion,
permitting an energy loss owing to the relatively small
20 fuel quantity which is converted when low engine loads
are implemented to be compensated. This permits
reliable operation of the internal combustion engine
with compression ignition even in low rotational speed
and load ranges. The current operating range with
25 compression ignition is thus made larger so that
further improved exhaust gas emissions can be obtained,
for example in the idling mode.

The main mixture can alternatively be spark-ignited by
30 means of an ignition source as a function of the load,
for example in the starting mode or in ranges with a
high load, in particular at full load.

The method according to the invention permits the
35 internal combustion engine to be operated with
compression ignition essentially at all load points or
in all load ranges without ignition misfires occurring.
The first fuel injection E1 permits an HCCI internal
combustion engine to operate at low loads, the

optional, third fuel injection E3 avoiding steep rises in pressure at high loads. The increase in the temperature in the combustion chamber at the top dead center LOT of the charge change ensures that as far as possible combustion can occur with compression ignition in every combustion cycle.

It is conceivable to omit the first fuel injection E1 and to carry out the method according to the invention with the second fuel injection E2 and the third fuel injection E3.